Color Temperature and Color Correction in Photography

In this document we discuss color temperature and color correction as it applies to photography. We are concerned with taking pictures - typically transparencies - rather than the development and printing of photographs.
If you have taken photographs under a variety of lighting conditions you will have noticed how the resulting images show a distinct color cast depending on the light source. In the image at the top of this document you will notice the blue-white color from the fluorescent tubes and the warm yellow-orange color from the tungsten lights over the fish.
Color temperature is the main way in which we measure the different colors and color correction is about filtration and other techniques that we as photographers use to achieve a desired color effect. (The desired effect may be a neutral "daylight" color, or any other effect, *e.g.* a slight warm-up effect for portraits.)
This document should be considered an introduction to the subject. I have included some links to additional material, but there is no substitution for going out there and trying for yourself. So read on and then pack your camera bag and try it out!

The Theory

> Learn everything, and you will see afterward that nothing is useless.
> — Hugo of Saint-Victor (12th century): On the Sacraments of the Christian Faith

This section may seem boring or unnecessary to some. After all, all the filters are labeled with their effect and the manufacturers publish long lists of which filter to use when. Surely you can just give us the techniques - after all, we do not need to know the theory behind the combustion engine in order to drive a car?
Call me old-fashioned if you like, but I think it is useful to have at least *some* understanding of the basic concepts. There are several reasons for this.
Firstly, I firmly believe that you remember things you understand better than tables and rules you have just learned by heart. Secondly, no table can cover all situations. An understanding of the principles will help you in new situations. And thirdly: it's *interesting!* So let's get on with it.

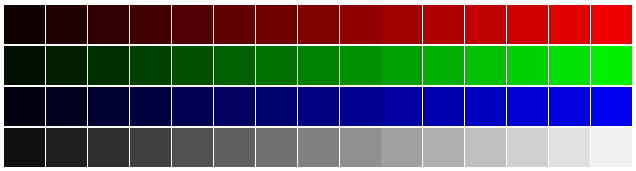
Color Balance

Film sensitivity: one, two, three, and four layers
This side bar contains a short history on the spectral sensitivity of films.

In the beginning there was black and white film. The early films were sensitive to only to blue light (and to some extent to invisible ultra-violet light). With this type of film you obtain white skies and black lips. Apparently people got used to this and considered these effects quite natural!
The next development was *orthochromatic* films. These extended the sensitivity of the earlier films into the green spectral area by adding another set of dyes. The benefits included a more natural tonal rendering of subjects and faster films.
Most black and white film that you can buy in the shops these days is *panchromatic* which means it is sensitive to all colors. If you ever wondered why so many black and white films have the word "pan" in their name (Kodak Tech Pan, Ilford Pan F, Fuji Neopan, ...) then you now know the reason: it was originally to distinguish these films from the earlier orthochromatic films and the name stuck. *Infrared film* is also available, but we will not discuss it here.
Then color films arrived. Most color films have three layers with dyes to record each of the three primary colors: blue, green, and red. Since all photographic dyes are sensitive to blue light to some extent, the blue-sensitive layer is usually on top followed by a yellow filter layer to prevent the blue light affecting the lower, green- and red-sensitive, layers. This layered structure is found in all modern color films, with some variations.
Three-layer color film work well in many situations and, with suitable filtration as discussed in the main article, can give excellent results under most lighting conditions. However, fluorescent light is becoming increasingly widespread and this particular light gives a characteristic green color cast to un-filtered photographs. For this reason, and for other difficult situations, Fuji has developed print (color negative) films with an additional fourth layer. This is a magenta layer and it does an excellent job of correcting this color cast without affecting the overall color balance. Originally introduced in the Reala films it is sometimes known as "Reala Technology" but it is now being made available in a much wider range of negative films, including the consumer Superia range and the professional portrait films (NPS).
This concludes this side bar discussion.

With a gross over-simplification - but one that is useful for this discussion - we can assume that film is sensitive to three colors. These roughly correspond to red, green, and blue - the traditional primary colors.
In this model, which is similar to what is used in computer graphics if that helps some of my readers with the following discussion, each point in the image can be described with three values. These could be chosen to be the percentage intensity of the colors red, green, and blue, relative to their maximum values for the particular film. This is completely analogous to the RGB color space in computer graphics.
Three values describe the image at any given point, but only two values are required to describe the color balance. Think of it this way: the overall intensity doesn't matter; if it is dark blue or light blue it is still blue. If you mix 25% of each of red, green, and blue you get a neutral gray color. If you mix 50% intensity you still get neutral gray, albeit a slightly lighter gray.

In the table below cells in the same row have the same color balance, only the intensity changes. All the colors in the first row are red, and red only with no trace of blue or green. (This may not be exactly true, depending on your monitor.)



We are of course free to choose any two (different) values to measure the color balance.
In photography it is traditional to choose as the two variables the ratio of blue to red and the ration of green to the overall intensity. These correspond to the traditional light-balancing filters (80, 81, 82, and 85 series filters), and green and magenta filters (CC-G and CC-M). More about this below.

Color Balance Variables	
Light Balance (LB), or Color Temperature	The ratio of the intensities of blue to red
Green-Magenta Balance	The relative amount of green

Color Temperature

Color temperature is a term that is borrowed from physics. In physics we learn that a so called "black body" will radiate light when it is heated. The spectrum of this light, and therefore its color, depends on the temperature of the body. You probably know this effect from everyday life: if you heat an iron bar, say, it will eventually start to glow dark red (*"red hot"*). Continue to heat it and it turns yellow (like the filament in a light-bulb) and eventually blue-white.
Be careful with the terminology here! The hotter the body gets (measured as the temperature in degrees Kelvin) the more the color moves from red to wards blue. But we say that red is a "warmer" color than blue! So a *warm body* radiates a *cold color* and a (comparatively) *cold body* radiates *warm colors*. I know, it's confusing...
The *photographic color temperature* is *not* the same as the color temperature defined in physics or colorimetry. As mentioned above, the photographic color temperature is measured only on the relative intensity of blue to red. However, we borrow the basic measurement scale from physics and we will measure the photographic color temperature in degrees Kelvin (K).
The following table should give you some feeling for the scale. These are of course not exact numbers but rather typical values. The list is *not* a substitute for a color meter.

Temperature	**Typical Sources**
1000K	Candles; oil lamps
2000K	Very early sunrise; low effect tungsten lamps
2500K	Household light bulbs

3000K	Studio lights, photo floods
4000K	Clear flashbulbs
5000K	Typical daylight; electronic flash
5500K	The sun at noon near Kodak's offices :-)
6000K	Bright sunshine with clear sky
7000K	Slightly overcast sky
8000K	Hazy sky
9000K	Open shade on clear day
10,000K	Heavily overcast sky
11,000K	Sunless blue skies
20,000+K	Open shade in mountains on a really clear day

This means that you will find photographers talking about *"daylight balanced"* film (nominally 5500K) and type A and B *tungsten balanced* films (3400K and 3200K). This gives the color of the light: below we will define a measure of how much a filter moves the color temperature (the mired shift).
For now remember that the color temperature is only half the story, albeit often the most important part of the story.

Filters

Now that we understand the two variables that define color balance, we need to tie this in to filters and define a way to express the effect and strength of a filter.

Light Balancing Filters

Light balancing filters are used to change the color temperature of light. If you place a light balancing filter in front of your lens, the overall temperature of the scene will be changed. These filters are sometimes called *conversion filters* because they may be used to "convert" daylight balanced film to use in tungsten light or tungsten films to use in daylight.

The filters are traditionally labeled in the Kodak Wratten system (I have no idea why they choose these names), and a typical selection is listed in the table below.

Blue filters				Amber filters			
Filter	**Exposure increase**	**Conversion**	**Mired**	**Filter**	**Exposure increase**	**Conversion**	**Mired**
80A	2	3200K to 5500K	-131	81	1/3	3300K to 3200K	+9
80B	1 1/3	3400K to 5500K	-112	81A	1/3	3400K to 3200K	+18
80C	1	3800K to 5500K	-81	81B	1/3	3500K to 3200K	+27
80D	2/3	4200K to 5500K	-56	81C	1/3	3600K to 3200K	+35
82C	2/3	2800K to 3200K	-45	81D	1/3	3700K to 3200K	+42
82B	2/3	2900K to 3200K	-32	81EF	1/3	3850K to 3200K	+53
82A	1/3	3000K to 3200K	-21	85C	2/3	5500K to 3800K	+81
82	1/3	3100K to 3200K	-10	85	2/3	5500K to 3400K	+112
				85B	2/3	5500K to 3200K	+131

As you can see, these filters are designed with daylight (5500K) and type B tungsten balanced films in mind. However, they are not limited to this.
A very useful concept is the *mired* shift. Mathematically, this is defined as

$$1000 * (1000/T2 - 1000/T1)$$

where $T1$ is the color temperature you have and $T2$ is the color temperature you desire (for example the color temperature of your film). The mired shift is sometimes called the *light balance* (LB) index of the filter, and it is listed in the table above.
There are two great things about the LB index for a filter:

1. It doesn't depend on the color temperature, and
2. It is additive.

The first point means that an 80A filter will not only change light with a photographic color temperature of 3200K to 5500K (as in the table), but also for example 2256K to 3200K - also a shift with a mired of -131.
The second point means that you can obtain a LB index that is not in the table by combining filters (*i.e.* placing more than one filter before the lens). Suppose as an example that you need to convert 11,000K (a clear bright day) to 5500K.

Using the formula above you know you need a LB index of 91 mired, so you might use a 85C with a 81 filter (+81+9 = +90 mired).

Gels

When I said that color temperature conversion filters are usually labeled with the Kodak Wratten number, then I was really only talking about filters that go in front of the lens. For *gels* that are used to change the color of artificial lighting (usually flash) we usually talk about "full", "half", "quarter", and even "eighth" CTO and CTB. CTO stands for **C**olor **T**emperature **O**range while CTB is - **B**lue. The full versions correspond to 85B and 80A and will shift the temperature about 131 mired in the appropriate direction.
It is a good idea to measure the actual color shift and not rely on the manufacturer. My full CTB shifts 2600K to 3610K on my color meter or about -108 mired. This is on continuous light. I tend to add a 80C filter to the lens for a slightly warm result on daylight balanced film, or a 81C on tungsten balanced film for spot-on color.
At least after this correction the light is white so I don't need additional color corrections. For the situations where this is not true, the next section describes the available remedies.

Color Correcting Filters

Color correcting filters typically come in the primary colors and their anti-colors as shown below, and in varying strengths from perhaps 2.5% absorption to 50%.

Color	Name	Effect
	Cyan	Absorbs Red
	Yellow	Absorbs Blue
	Magenta	Absorbs Green
	Red	Absorbs Blue and Green
	Green	Absorbs Red and Blue
	Blue	Absorbs Red and Green

The filters are usually labeled like CC*nnX* where *nn* is the peak absorption and *X* is the first letter of the color. So CC10C is a pale cyan filter while CC50B is dark blue.
As we have discussed for photography we only need to control the amount of green once the color temperature has been adjusted. This means that as a photographer you only need to carry a set of green (CC--G) and magenta (CC--M) filters in addition to your color temperature filters. This is simpler than having to carry six sets.
This does not imply that the other color correcting filters have

no use; indeed they are often employed in the printing of images. However that is not our main focus here so we'll leave that for another article.

Practical Applications

To be completed....

Color Meters

The two main producers of color meters are Grossen and Minolta. There does not seem to be much difference in performance and capabilities between the two brands. Avoid other brands unless you are *very* sure you know what you are doing.
Color meters are not cheap: expect to pay a few hundred quid (that's pounds sterling for you foreigners) for either brand.
My meter is a Minolta Color Meter IIIF. I'm happy with it: it is accurate and easy to use.
The basic functions that it perform are:

- Measure color temperature of ambient light
- Measure color temperature of mixed flash and ambient light
- Measure color temperature of only the flash component of mixed light

The flash measurements can be performed with or without a sync cord.

Light box and other lights for viewing pictures.
After you have gone through all the trouble of color correcting your images on location when you expose them then please do not forget to view them in white light! This means light calibrated to 5500K.
Ideally you should check the calibration of your viewing system regularly. But be aware that the color meter you use on location (*e.g.* the Minolta IIIF) is *not* suitable for for this calibration. This is because this color meter is calibrated for film, but you need to calibrate for the human vision which has a different spectral sensitivity.
You can use special color meters for this purpose. Minolta recommends their Chroma Meter CL-100. Additionally, since color temperature does not completely specify a color (as we have seen above) you must calibrate both components of the light. In the CIE color specification system, photographic daylight has the coordinates $x=0.332$ and $y=0.348$. For more information on systems of color specification, see pages 327-333 of Leslie Stroebel, *et al.*: Basic Photographic Materials and Processes, discussed in the resources section below.

Realistically, you are not going to own such a specialized instrument. You have two options. One is to have your light board checked by a qualified lab a regular intervals. The other is simply to remember to change the tubes in the box frequently and at least as often as the manufacturer recommends.

The output is the color temperature and the required green - magenta color correction (CC). The color temperature can be displayed in Kelvin, mired (Light Balance (LB) index, see above) or - and this is very useful on location where you are busy enough without having to remember the finer points on color correction - directly in the filter you need to use.
For example, where I'm writing this, my meter suggests that I use a 80B plus an 82 filter to correct the temperature, and a 26 magenta filter for the green balance. I need a mired of LB=-126 to correct daylight film. For type B tungsten film I only need the magenta filter (LB=+4, CC=26M). Clearly the light here is awful...

Do I have a Type A or Type B Tungsten Film?
The quick answer is: you have a Type B tungsten balanced film (3200K).
As far as I know, the only Type A film that is currently in anything that remotely resembles production, is the Kodakchrome 40 (5070) film. You *never* see it in the shops, so there is zero chance that you have purchased it by mistake.
All the current films that you may be able to btain in a professional photographic materials shop, including Kodak Ektachrome 64/160/320 T (EPY/EPT/EPJ) and Fuji RTPII, are Type B films balanced for 3200 K tungsten lights.

In any case the operation is dead simple: select your film type (daylight, or Type A or B tungsten film) press the power button, point the white dome at the light source, and press the measure button. Presto. For flash light set the exposure time from 1s to 1/500s and press the measure button. Don't forget to fire the flash. The special exposure time 'F' measures the flash color temperature in mixed light.
That's really all there is to it. Except it isn't: there is one very important feature left. Memory channels.
The meter is calibrated for films that will render colors neutral at 5500K, 3400K, and 3200K (daylight, and type A and B tungsten films, respectively). But you are a careful photographer, and you experiment with filtration until you find the color temperature that gives *you* just the right colors for *your* subjects. It's unlikely to be 5500K or 3200K exactly.

For example, Will Crockett (see resources below) feels that Fujichrome Astia (RAP), which is a daylight balanced film, reproduces skin tones faithfully in light with a color temperature of 5150K - quite a way from 5500K. Will is a portrait photographer, so it is very important for him to have accurate skin tones. (This is of course why he carfully tested his film and why you should also test your film with the type of subjects you most often photograph.)
What is he going to do? Calculate mired values every time he has to make an exposure? No, he can simply select a memory channel and store a mired of LB=1,000*(1,000/5,150 - 1,000/5,500)=+12. Every time he uses the meter in that channel after this, it will automatically compensate with 12 mired and give him the temperature he desires. You can store nine films in this manner, and for each film you can store not only the mired (LB) value, but also the green-magenta color compensation you need. No more reciprocals in the head on location!

Complications...

Things are never that easy. To be completed...

Resources

Photographers

- Will Crockett is a Chicago based professional photographer and on his web site he provides excellent advice on most aspects of commercial portraiture, including color correction. His *Pocket Guide* is a treasure.

Products

- Lee filters sets the standard for system filters (the ones that go in a holder in front of the lens as opposed to screwing into the filter ring on the lens) and for lighting filters ("gels").

Shops

- Speed Graphic in the UK has almost everything, and does a nice mail-order business. I buy most of my "little things", including filters, from them. Their range is truly comprehensive and they only do photographic equipment. As they say: their catalog is "guaranteed to contain no video, no audio, no hi-fi, no refrigerators". Color meters are not listed, but they will be happy to get one for you and last time I called they had the Minolta in stock. US customers should be able to find something more local.

Books

Leslie Stroebel, *et al.*: Basic Photographic Materials and Processes

Is this the best book about photography ever written? All the authors are from the School of Arts and Sciences at Rochester Institute of Technology, and this volume takes the form of a university textbook. It is *extremely* comprehensive. A book to own, to read, and to re-read many times.

Leslie Stroebel: View Camera Technique

More specialized than the book mentioned above but a classic tome about photography. Don't be misled by the title: sure it is about view cameras, but they are very basic cameras and understanding them will teach you much about photography, even if you only ever use a 35mm camera.
